ACEEE Int. J. on Information Technology , Vol. 3, No. 3, Sept 2013

Pedestrian-traffic Logging Unit with Tailgating DetectionUsingRange Image Sensor

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***Abstract*—This paper proposes a method for logging people whichpass through a gateway in buildings or regions. The proposed method detectsunexpected passing called *tailgating*. The *tailgating* means that anon-identified person tries to enter or leave a room by tagging after anotheridentified person. The tailgating person does not appear on the log recordedby conventional identification systems. The proposed method logs the passingin a person-unit by using cameras and a range image sensor. Firstly, thenumber of people in front of the card reader is counted by the range imagesensor. Secondly, the camera image taken at the same time as the identificationis separated individually based on the projected range image. Lastly,the passing is logged in a person-unit. The tailgating person is logged withthe individual camera image and the ID of the inviter. Experimental resultshave demonstrated that the prototype of the proposed method can obtainthe log of the passing including tailgating people.**

***Index Terms*—logging pedestrian traffic, tailgating detection, range imagesensor, sensor fusion**

I. Introduction

People are often identified to open a door and to passthrough a gateway with their identification card or their ownbodily characteristics, and the events are logged atthe same time [1][2]. The log is utilized for analyzing orcontrolling traffic of pedestrian similar as car traffic analysis[3]. For example, a displacement of the person is applicablefor marketing at a store. In addition, a throughput ateach gateway is useful information for controlling the number of peoplebetween the gateways. It is desirable that a person-unitlog is obtained instead of an event-unit log by the existingidentification systems to utilize the log in above cases.

To log the people correctly, a problem called tailgatingshould be considered. Tailgating means tagging afteranother identified person to skip the identification. Fig.1 shows an example of the tailgating. Person of rightside passes through the gateway by tagging after left personwho has been identified. The person who passes throughby tailgating does not appear on the log. It is desirable thatthe tailgating is detected precisely in order to analyze thepedestrian-traffic precisely. However, in case that the peopleare identified for logging the events and analyzing thetraffic of people, the conventional tailgating-detection systemsneed a cumbersome procedure.

We propose a method for logging the passing of peopleat a gateway even if a person passes through the gatewayby tailgating. Besides, the method aims at logging thepeople without cumbersome procedures when people passthrough the gateway. We focus that all tailgating personspass through the gateway with an identified person. We definethe identified person as a potential inviter of the tailgatingperson. The proposed method can improve an accuracyof the pedestrian-traffic analysis with the person-unit log. Inaddition, the users do not have any extra procedures forthe identification. In this paper, we show a logging unit withtailgating detection using cameras and a range image sensor.The proposed method can log the passing in a person-unitby using the cameras and the range image sensor in additionto card readers for identification. Firstly, a number ofpeople in front of the card reader is counted by the range imagesensor. Secondly, the camera image taken at the sametime as the identification is divided into individual regionsbased on the range image. Lastly, the passing is logged ina person-unit. The identified person is logged with his/herown ID. On the other hand, the tailgating person is loggedas the tailgating people with the ID of the person identifiedat the same time and the individual camera image.

The proposed method has two major advantages over other conventional methods as the following. Firstly, a person-unit log is obtained by using the proposed method. The conventional event detection methods have detected and logged in an event-unit. The proposed method enables to log the event in a person-unit, and it is useful to analyze the pedestrian-traffic. Secondly,the proposed method is robust over colors and lightings of a target scene to detect the tailgating.A prototype has been implemented to show the advantages above, and experimentalresults have demonstrated that the prototype of theproposed method can obtain the log of the passing includingthe tailgating people.

II. Related Works

The tailgating is serious problem in a field of car traffic analysisfor both precise toll collection and traffic control [4][5].Similarly, the tailgating should be considered for precisepedestrian traffic analysis.

Basic idea for preventing the tailgating is forcing usersalone when they are identified. A personal room which

DOI: 01.IJIT.3.3.1

Figure 1. An example of person entering a locked room by tailgating. The left person is identified by theentry control system to open the door. On the other hand, the right person enters the room by followingthe identified person. The tailgating person is not logged in this case

includesan identification system and a gate [6] is effective fortailgating prevention and utilized in fortified rooms or buildings.Various technologies are also used for the tailgatingdetection. A mass sensor which is set on a floor of the identificationarea [7], and an infrared beam [8][9] are used intopractical uses for counting the number of people in front ofthe gate. And a thermal sensor are also used for the tailgating detection [10][11]. The methods are intended to shutout the tailgating person if the tailgating is detected for thesecurity. However, in case that the people are identified forlogging the events and analyzing the traffic of people, suchtailgating detection may be regarded as a cumbersome procedurefor the users.

Several camera-based methods for passive observingand tracking the human flow have been proposed. Elguebaly*et al*. has proposed the method for separating an image intoindividual regions in variable environments [12]. The camerasare also used for human gait extraction and recognitionfor human motion analysis [13][14]. Similarly, footsteps ofthe people are also visualized from top-view cameras [15].The top-view camera is effective to avoid an occlusion. Onthe other hand, the camera-based methods are sensitive tochange of the lighting. The camera-based methods is notsuitable when the gateway which is set at the uncertain lightings.

We have proposed the method for logging and the analyzingthe identified people using cameras in combinationwith other sensors [16]. In this paper, we propose a methodfor logging the people with tailgating detection by introducinga range image sensor.

III. Proposed Method

The proposed method is for logging people who passthrough a gateway including the tailgating people. Camerasand a range image sensor are used for the proposedmethod in addition to an identification system. The proposedmethod is to detect the tailgating persons whom theconventional identification systems [17] cannot detect.

A. Configuration

Fig. 2 shows an overview of the proposed method. Theproposed method consists of cameras to take pictures, arange image sensor to count a number of people and cardreaders to identify people. Several methods for countingand identifying people from camera images have been proposed[18][19][20]. However, it is difficult to detect and count the people correctly using only cameras in the tailgatingsituation, because the tailgating person is mostly closeto another identified person to pass through the gateway atthe same time as the identified person. So we introduce arange image sensor in combination with the cameras to detectand count the person correctly. The cameras are set atfront and behind the gate to take the pictures head on. Therange sensor is attached to the roof. A range image is captureddownward to avoid occluding. To detect and analyzeonly human-height objects, the range image is thresholdedby as following:

$$\mathrm{dst}(i.j) = \begin{cases} \mathrm{src}(i,j) & \text{if } \mathrm{src}(i,j) \geq t_{\mathrm{h}} \\ 0 & \text{otherwise} \end{cases}, \tag{1}$$

where $\mathrm{src}(i$ and $\mathrm{dst}(i$ is depth value of the source andthe thresholded range image, respectively.

B. Calibration between Sensors

Fig. 3 shows a relationship between coordinate systemsused in the proposed method. A given point $(x_{\mathrm{r}}, y_{\mathrm{r}}, .$ on arange image is projected onto a point $(x_{\mathrm{cam}}, y_{\mathrm{ca}}$ on a cameraimage coordinate system as following:

$$\begin{bmatrix} hx_{\mathrm{cam}} \\ hy_{\mathrm{cam}} \\ h \end{bmatrix} = \mathbf{P}_{\mathrm{cam}}\mathbf{P}_{\mathrm{r}}^{+} \begin{bmatrix} x_{\mathrm{r}} \\ y_{\mathrm{r}} \\ z_{\mathrm{r}} \end{bmatrix}, \tag{2}$$

where $\mathbf{P}_{\mathrm{cam}}$ is a 3*4 transformation matrix from world coordinatesystem to camera image coordinate system, and $\mathbf{P}_{\mathrm{r}}^{+}$ is a 4*3 transformation matrix from range image coordinatesystem to world coordinate system. Note that $\mathbf{P}_{\mathrm{r}}^{+}$ is apseudo-inverse matrix of $\mathbf{P}_{\mathrm{r}}$,which is a transformation matrixfrom world coordinate system to range image coordinatesystem.

A reference object is utilized for calibrating between the range image sensor and the cameras. Figs. 4 (a) and(b) are a side-view and a top-view of the object, respectively.The reference object defines the world coordinate system,and corner points on the reference object are used as a referencepoint. At least 4 reference points should be visible fromthe range image sensor, and at least 6 reference points alsoshould be visible from the cameras to calibrate between therange image

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sensor and the cameras. Figs. 5 (a) and (b)are examples of images taken by the camera and the rangeimage sensor, respectively. The reference points can be locatedin both images from their photometric or geometricfeatures of the reference object. And then, $\mathbf{P}_{cam}$ and $\mathbf{P}_r^+$ areestimated by calculating pseudo-inverse matrix [21].

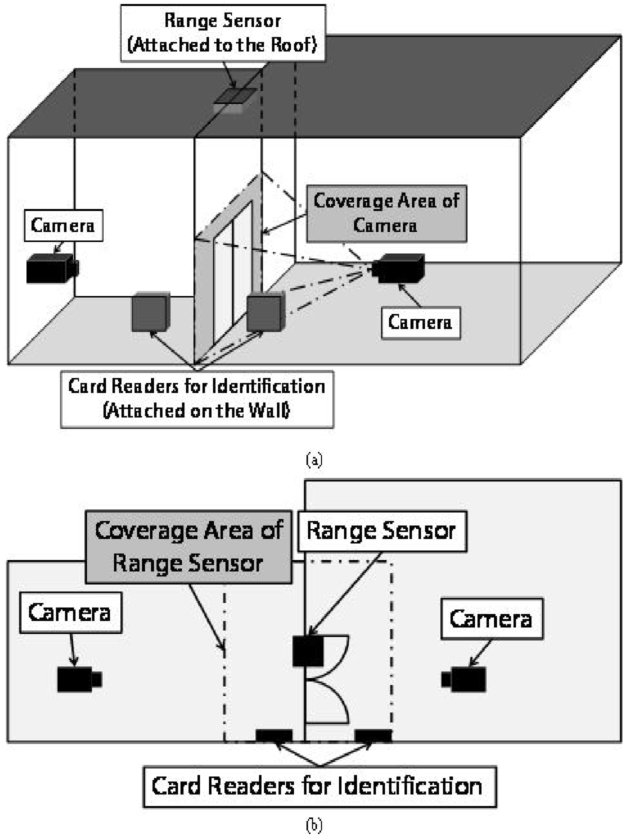

Figure 2. An overview of proposed logging unit. The proposed unit consistsof cameras and a range image sensor to detect tailgating in addition to cardreaders. (a) Side view of the unit. The cameras are set at the front of thedoor. (b) Top view of the unit. The range image sensor is attached to theroof.

C. Dividing Range Image and Camera Image

The range image is divided into separated individual regionsand projected onto the camera image to divide the cameraimage into separated individual regions.

1) Dividing Range Image

Firstly, non-zero pixels in the range image are labeled. Itshould be considered that labeled region consists of two ormore persons when the persons are close to each other. Thenumber of the people in the region is estimated from a shapeof *projection histogram*. Fig. 6 (a) shows an input rangeimage and obtained projection histogram. Principal ComponentAnalysis (PCA) is employed to determine two coordinateaxes and newly at each label. The axes are parallel to the first principal component and the secondprincipal component by the PCA, respectively. And an originof the axes is identical with left lower point of the rangeimage. The projection histogram $\sigma(c)$ is obtained as:

$$\sigma(c_i) = \sum_s r(c_i, s), \tag{3}$$

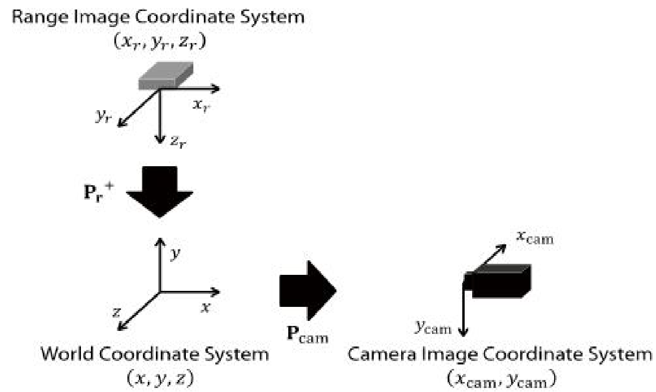

Figure 3. Coordinate systems used in the proposed unit. Range image coordinatesystem (x_r, y_r, z_r) is converted into world coordinate system (x, y, z) with a projection matrix $\mathbf{P}_r^+$. On the other hand, the world coordinatesystem is converted into camera coordinate system (x_{cam}, y_{cam}) with a projectionmatrix $\mathbf{P}_{cam}$. To calibrate between the range image sensor and thecameras, Reference object is set and observed

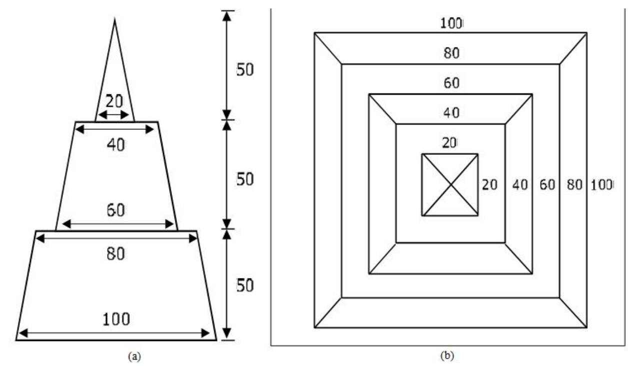

Figure 4. A reference object for calibrating between the cameras and therange image sensor. Corner points are used for the calibration, and theposition of the corners in the world coordinate system are known. At least4 points should be visible from the range image sensor, and at least 6 pointsshould be visible from the cameras. The unit of the length in the figures isa centimeter. (a) Side view of the box. (b) Top view of the box.

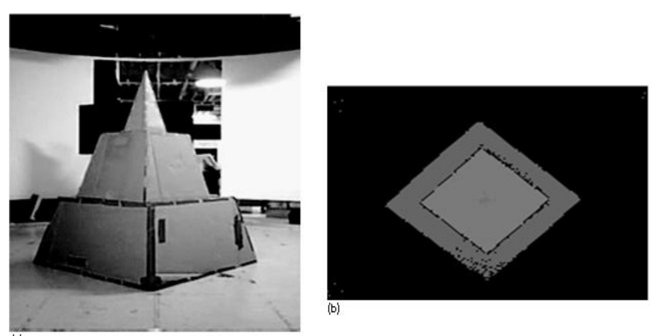

Figure 5. Images captured by the camera and the range image sensor in casethat the target is the reference object shown in Fig. 4. The corner pointscan be located in both the camera image and the range image. (a) Capturedimage taken by the camera. (b) Captured image taken by the range imagesensor. Note that the image is described as the false-color image.

where (c_i, s) is the value of the range image on the (c,s) coordinate system in Fig. 6 (a), and $c_i \in C$. Let $l_{bp}(c)$ be theline from $\sigma(c_{begin})$ to $\sigma(c_{peak})$, and $l_{bp}(c)$ be the line from $\sigma(c_{peak})$ where C_{igin} is the smallest

DOI: 01.IJIT.3.3. 1

value of where $\sigma(c) \geq 0$, C_{peak} is the value of when has themaximum value and is the largest value of where. As shown in Fig. 6 (c), it is assumed that theshape of the histogram is similar to the lines andwhenthe region consists of single person. On the other hand, theshape of the histogram is nt similar to the lines andwhen the region consists of two or more persons, as shownin Fig. 6 (d). The sum of the squared difference betweenthe lines ,and the histogram is calculatedas:

$$d = \sum_{c=c_{\text{begin}}}^{c_{\text{peak}}} \left(l_{\text{bp}}(c) - \sigma(c) \right)^2 + \sum_{c=c_{\text{peak}}}^{c_{\text{end}}} \left(l_{\text{pe}}(c) - \sigma(c) \right)^2 \quad (4)$$

The region is divided at the line corresponding to the *valley* of the histogram if $d \geq t_d$, where td is constant.Theprocess is repeated recursively until $d < t_{\text{d}}$ for all regions.Fig. 6 (b) shows the divided range image.

2) *DividingCamera Image*

Camera image is also divided into separated individual regionsaccording to the divided range image. Fig. 7 showsan example of the process. Firstly, visible pixels are extractedfrom the range image. The nearest foreground pixelon a line of sight corresponding to each pixel of the cameraimage is extracted from the range image. Secondly, anexistence region of each person is estimated on the horizontalaxis of the range image shown in Fig. 7 (a). Lastly, theestimated existence regions are projected onto the cameraimage, and mask images corresponding to each person aregenerated as shown in Fig. 7 (b).

D. Logging People Including Tailgating Person

Incase that persons pass through the gateway at the sametime, there are always one inviter and *n-1* tailgating persons.The tailgating person is logged with the personal IDnumber of the inviter, because the inviter may have a responsiblefor the tailgating. In addition, the camera imagecaptured at the same time as the identification is dividedinto separated individual regions.

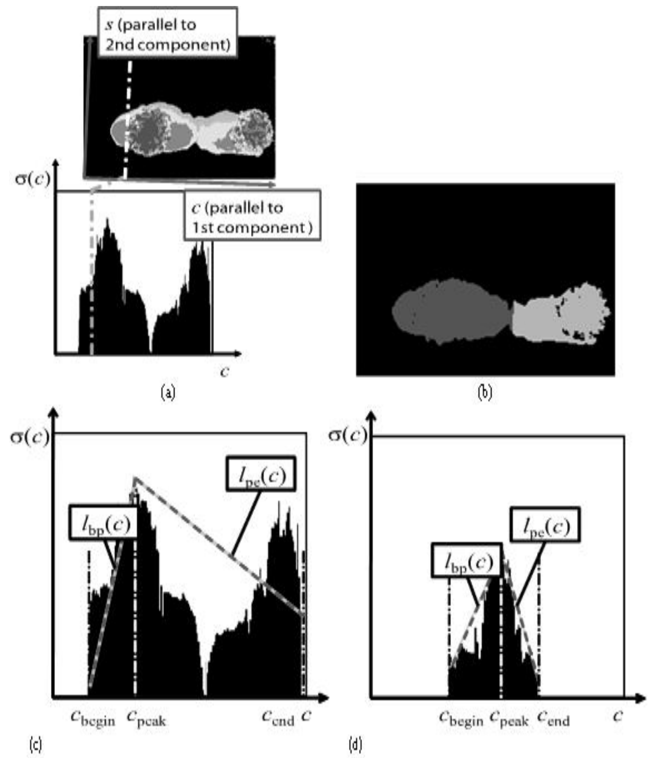

Figure 6. Dividing a region into separated individual regions based on PrincipalComponent Analysis (PCA). (a) Two axes c and s, which are respectivelyparallel to the first principal component and the second component,are determined at each labeled region. Then, projection histogram $\sigma(c)$ isobtained. (b) Divided regions by the proposed method. (c) An example ofthe histogram in case that the region consists of one person. (d) An exampleof the histogram in case that the region consists of two persons.

The individual images arelogged. The proposed system assumes that the closest personto the card reader is the identified person and others arethe tailgating person on the camera image.

IV. Experimental Results

A prototype of the proposed method was implemented. Experimentalsettings and results by the prototype are writtenbelow.

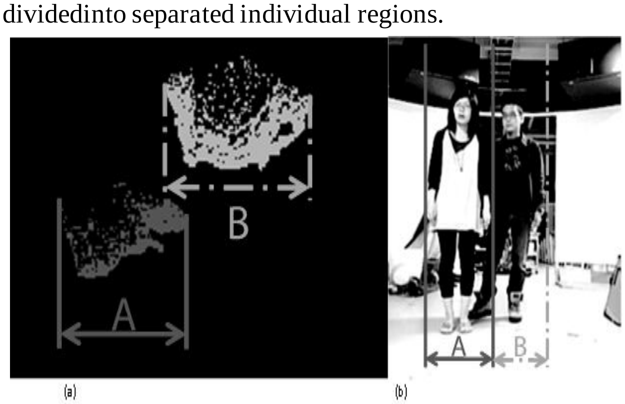

Figure 7. Dividing camera image into individual images. (a) Extracted visiblepixels on the range image. An existence region of each person A and Bis estimated on the horizontal axis of the range image. (b) Projected existenceregions onto the camera image. The individual images are extractedusing the existence regions.

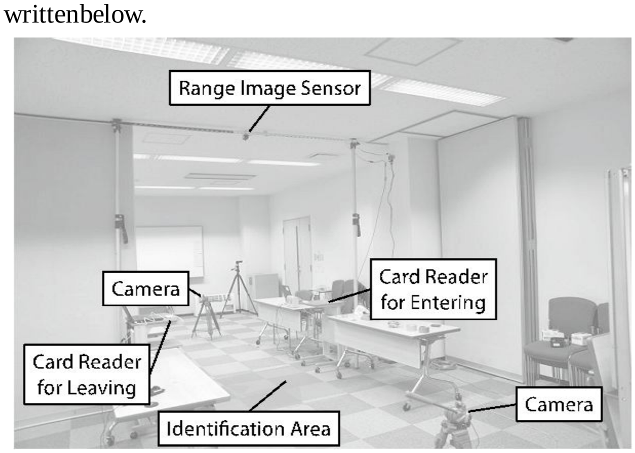

Figure 8. An overview of the experimental settings. It is assumed that theidentified person is always leftmost person on the camera image, becausethe card reader is set at the left side of the sight of the camera correspondingto the card reader.

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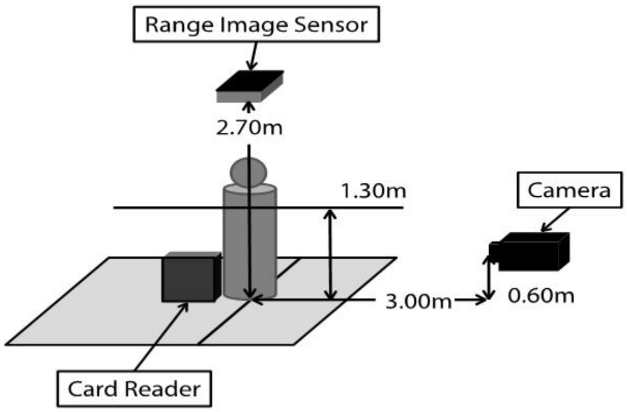

Figure 9. Positions of the range image sensor, the camera and the cardreader. The camera was set at 0.60 meters high from the ground level.The object appeared on the range image in case that the height of the objectwas taller than 1.30 meters.

A. Settings

Fig. 8 shows an overview of the experimental settings.The range image sensor was MesaImagingSwissRangerSR3000. The width and the height of the captured rangeimage were 176 and 144 pixels, respectively. A frame rateof the range sensor was 25 frames per second on average.The range image sensor was set at 2.70 meters high from theground level. Two Logitech Qcam were used in the experiment.Camera images were captured at the same time as theidentification with the card reader. The width and the heightof the camera image were 320 and 240 pixels, respectively.In addition, two of SONY PaSoRi RC-S320 were used as cardreaders for the identification. The users were identified bytouching their own identification card to the reader. In theexperiment, it was assumed that the identified person wasalways leftmost person on the camera image, because thecard reader was set at the left side of the sight in the camerafacing to the users. And the size of the identification areawas determined by the view angle and the altitude of therange image sensor. In the experiment, the width and theheight of the identification area were 2.00 and 1.50 meters,respectively.

Table I. Experimental Results

Method	Trial	Tailgaters	Detected tailgaters
Proposed method	1	52	38
	2	30	24
Han *et al.* 2004 [20]	1	37	35
	2	45	42

Fig. 9 shows the positions of the camera and therange image sensor in the experiment. The camera wasset at 0.60 meters high from the ground level and horizontalposture. The threshold to extract human-height object $t_h = 1.30$. The object appeared on the range image in casethat the height of the object was taller than 1.30 meters. Inaddition, the threshold for dividing the region on the rangeimage $t_d = 1000$ in the experiment.

In the experiment, One to three persons formed groupsrandomly at each passing. It indicates that one personpassed through the gateway with the identification, and other0 to 2 persons tried to pass through the gateway by tailgating.

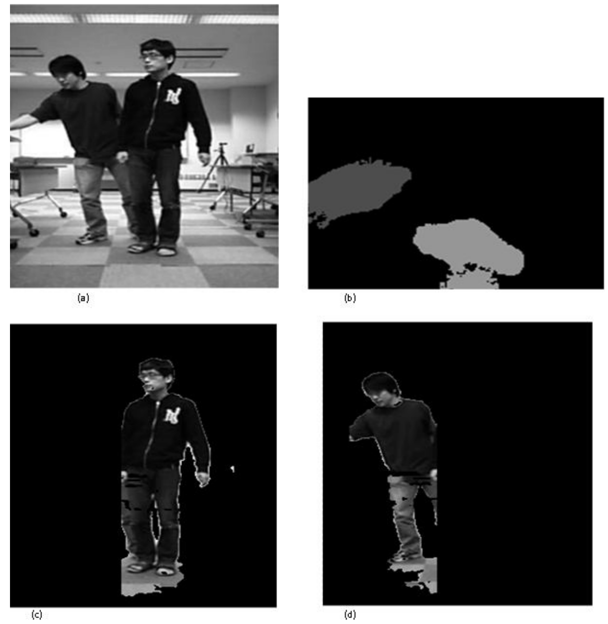

Figure 10. Divided individual images by the prototype in case that 2 personspassed through the gateway at a time. (a) Camera image captured by thefront camera. (b) Range image captured at the same time as the cameraimage. (c) Divided individual image of the left person. The person wasestimated to be identified. (d) Divided individual image of the right person.The person was estimated to enter by tailgating.

B. Experimental Results

Table I shows experimental results by the prototype. Itshows that 82 persons tried to pass through the gatewayby tailgating, and 62 persons were logged by the proposedmethod.

Figure 11. Divided individual images by the prototype in case that 3 personspassed through the gateway at a time. (a) Source image captured bythe front camera. (b) Divided individual image of the left person. Theperson was estimated to be identified. (c) Divided individual image of thecenter person. The person was estimated to enter by tailgating. (d) Dividedindividual image of the right person. The person was also estimated to enterby tailgating.

Fig. 10 shows an example of the divided individualimages. Fig. 10 (a) is a source image captured by the frontcamera at the same time as the identification. Fig. 10 (b) is arange image at the same time as the identification. Figs. 10(c) and (d) are divided individual images. In this case, rightperson tried to enter by the tailgating. The prototype succeededin counting the number of the person in front of thecard reader correctly, and individual images were recordedby the proposed method. Fig. 11 also shows an exampleof the dividing. Fig. 11 (a) is a source image captured at thesame time as the identification. Figs. 11 (b), (c) and (d) aredivided individual images. The left person (b) was estimatedas the identified person and logged with his own ID number.The person(d) were estimated as the tailgating person and logged withthe ID number of the left person.

C. Discussions

The failure cases in the experiment and the limitation of theproposed method are discussed in this section. In the caseshown in Fig. 12, the left person did not appear on therange image. This is because the region was divided mistakenly by the noise, and the smaller fragments of the humanregion were removed by labeling as a circled region inFig. 12 (b). Fig. 13 shows another example of the failurecases. As shown in Fig. 13 (b), the region was correctly extractedin the case. However, it was estimated wrongly thatthe region contained three persons due to the extra borderlineas shown in Fig. 13 (c). A major cause of the errors wasa noise on the range image. The range images have limitedresolutions and contain much random noises.The proposed method has been not yet suitable for ahigh-security gate control, because the detection rate ofthe proposed method is still lower than 80%. To increasethe accuracy, it is discussed that the time-sequential rangeimages are introduced. In addition, we are planning to introduceother kinds of sensors in combination with the methodproposed in this paper.The proposed method was also compared to the conventionalimage-based method proposed by Han et al. [20]in TableI. The detection rate of the proposed method islower than the rate of the method [20]. However, the proposedmethod has succeeded in dividing contiguous groupinto individual images, and the number of the people in thegroup was counted. It is difficult for the conventional image-basedmethods. In addition, the proposed method is robustover colors and lightings of the scene, because the methodemploys an infrared range image sensor. It means that theproposed method would be used in dark scenes, such as agate at night or a darkroom. We are also planning to test theproposed method in such situations.

V. Conclusions

In this paper, the method for logging traffic of pedestrianwith tailgating detection has been proposed. The proposedmethod consists of cameras and a range image sensor in additionto an identification system. The people are capturedby the range image sensor and the cameras simultaneously.The regions are separated into the individual regions utilizingthe shape of the human. The number of the people iscounted from the separated range image, and the enteringand the leaving are logged in a person-unit with the individual camera image.

The experimental results have demonstrated that thetailgating people were newly logged by the prototype of theproposed method even if people tried to pass through thegateway by the tailgating. On the other hand, there weresome failure cases. The region in the range image was notdivided correctly due to the noise on the range image.

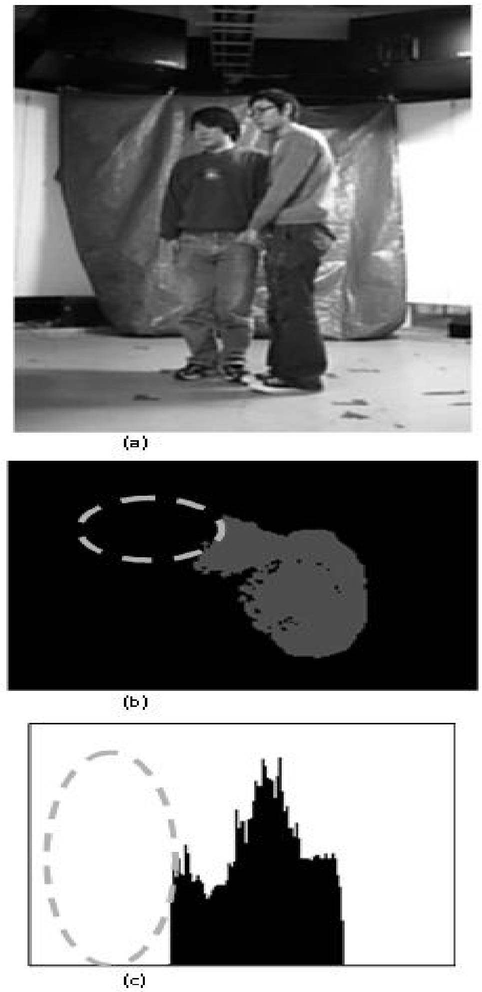

Figure 12. An example of the failure case. (a) Camera image captured bythe camera. (b) Range image. The fragment is missing in circled area. (c)Projection histogram corresponding to the range image (b). It was assumedthat the region contained one person due to the missing fragment.

The proposed method can improve the accuracy of thepedestrian-traffic analysis based on a person-unit loggingwith the tailgating detection. It indicates that more efficientmarketing in the store will be realized in the system. Besides,the proposed unit does not increase the complexity forthe users compared to the conventional tailgating preventionmethods. The proposed method would estimate and recordother characteristics of the users, such as height, weight andgender from the camera images and the range images. Thecharacteristics would be effective for the marketing analysis.

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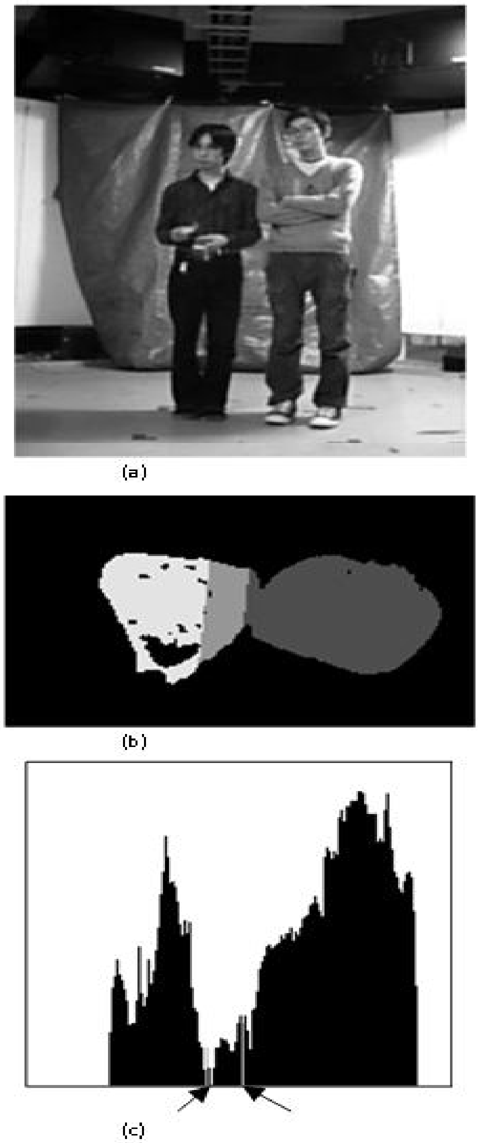

Figure 13. Another example of the failure case. (a) Camera image capturedby the camera. (b) Range image. (c) Projection histogram corresponding tothe range image (b). It was assumed that the region contained three personsdue to the extra borderline. Two arrows indicate the border-lines.

Future works will aim at logging persons by multipleunits set at several gateways and analyzing the pedestrian-traffic.And we are planning to obtain further informationfrom the camera images and range image, such as a result offace recognition.

ACKNOWLEDGMENT

This work was supported in part by Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number 24700092.

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